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THE GROUNDING OF ELECTRIC SYSTEMS IN AND AROUND MINES

BY

L. C. ILSLEY

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By L. C. Ilsley[2]

IMPORTANCE OF GROUNDING

From the standpoint of electrical safety the question of grounding is one that can not be overlooked or treated lightly. The presence or absence of a ground connection to a piece of electrical machinery or a sheath of a cable may mean the saving or loss of a human life. Therefore, to minimize shock hazards, if for no other reason, grounding should be resorted to whenever it will provide additional safety. Economically, also, grounding of equipment is very necessary. Hundreds of thousands of dollars are saved to the industry each year by properly placed grounds.

In the United States less attention is paid to grounding in mines than in Great Britain. For this reason there are proportionately more men killed from electric shock here than in that country; a considerably larger loss in electrical failures or breakdowns of electrical equipment undoubtedly results.

Speaking broadly of mining conditions in the United States, there seems to be an unwillingness on the part of the industry to provide adequate grounding systems for underground electrical equipment. This lack makes the problem of safeguarding such equipment extremely difficult and leaves many mines in a state bordering on continuous hazard.

The present paper, which consists chiefly of a compilation of the best available rules and suggestions on grounding, has been prepared in hopes of creating greater interest in the subject of grounding, and in order that such material might be more readily available to mine electricians and others having to do with electrical installations in and about mines.

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UNDERWRITERS' REQUIREMENTS FOR GROUNDING APPARATUS AND CIRCUITS

The National Electrical Code contains regulations of the National Board of Fire Underwriters for electric wiring and apparatus covering the question of grounding under Article 9 of the code. The rules covering grounding were recently revised by a special committee and became efective January 1, 1930. Underwriters' requirements for grounding, which have been prepared from the standpoint of preventing fires, have a general application to all electrical equipment installed outisde mines and can be applied equally as well to much of the underground equipment and wiring. Article 9 follows:

ARTICLE 9. GROUNDING

This Article treats primarily of protection in the use of electrical circuits and equipment by grounding, but where in this code protection by insulation or isolation is deemed effective these methods are recognized as alternatives.

901. General

a. Where low-potential circuits, arresters, equipment, conduit, armored cable, metal raceways and the like are grounded as a protective measure, they shall be so arranged that there will be no objectionable passage of current over the grounding conductors. The temporary currents, which are set up under accidental conditions while the grounding conductors are performing their intended functions, are not to be considered objectionable. Where an objectionable flow of current occurs over a grounding conductor, due to the use of multiple grounds, (1) one or more of such grounds shall be abandoned, or (2) their location shall be changed, or (3) the continuity of the conductor connecting the grounding connections shall be suitably interrupted, or (4) other means shall be taken to limit the current.

b. The grounding connection, including electrode and grounding conductor, shall be permanent and effective and shall always be made on a continuous-metallic underground water-piping system if one is available, the grounding connection shall be made in a manner to secure the most effective ground and by any of the following methods:

(1) The metal frame of the building, when effectively grounded;

(2) A continuous metallic underground gas piping system;

(3) A local metallic underground piping system, metal well casing and the like; or

(4) An artificial ground whose electrode consists of a driven pipe, driven rod, buried plate, or other device approved for the purpose.

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d. Where artificial grounds are used they shall, as far as practicable, be embedded below permanent moisture level. Each buried-plate electrode shall present not less than two square feet of surface to exterior soil. Electrodes of plate-copper shall be at least 0.06 inch in thickness. Electrodes of iron or steel plates shall be at least $\frac{1}{4}$ inch in thickness. Electrodes of iron or steel pipe shall be galvanized and not less than $\frac{3}{4}$ inch internal diameter. Electrodes of rods of steel or iron shall be at least $\frac{3}{4}$ inch minimum cross-section dimension. Approved rods of non-ferrous materials or their approved equivalent used for electrodes shall be not less than $\frac{1}{2}$ inch in diameter. Driven electrodes of pipe or rods, when of less than standard commercial length shall preferably be of one piece and shall be driven, except where rock bottom is encountered, to a depth of at least eight feet regardless of size or number of electrodes used.

e. The combined resistances of the grounding conductor and its connection with the ground shall not exceed 3 ohms for water-pipe connection nor 25 ohms for buried or driven grounds. Where it is impracticable to obtain with one ground artificial ground resistance as low as 25 ohms, this requirement shall be waived, and two artificial grounds, at least six feet apart and with combined area of not less than four square feet, shall be provided.

It is recommended that ground connections when installed be tested for resistance particularly when multiple grounding to water-pipe is not used.

f. Where a system ground conductor or secondary neutral grid is employed it shall be effectively grounded at intervals which will satisfy the requirements as to current-carrying capacity and resistance prescribed in this Article.

902. Grounding Distribution or Supply Systems

The provisions of this Section apply only to distribution or supply systems which are electrically connected to interior wiring systems and with respect to the protective grounding of such interior wiring systems.

a. Two-wire direct current systems supplying interior wiring systems and operating at not to exceed 300 volts between wires shall be grounded on one conductor and at the supply station, but not at individual services.

It is recommended that two-wire direct-current systems be grounded in the same manner if a neutral point can be established and if the maximum difference of potential between the neutral point and any other point on the system does not exceed 300 volts. It is recommended that two-wire direct-current systems be not grounded if the voltage to ground of either conductor would exceed 300 volts after grounding.

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b. Three-wire direct-current systems supplying interior wiring systems shall be grounded on the neutral at one or more supply stations, but shall not be grounded at individual services.

c. Secondary alternating-current distribution systems supplying interior wiring systems shall be grounded if they can be so grounded that the maximum voltage to ground does not exceed 150. Similar systems operating with the voltage to ground exceeding 150 volts may be grounded. The ground connection for a grounded secondary alternating current distribution system shall be made, except as provided below, on every individual service. Additional ground connections may be made on the leads of the transformer or transformers or at one or more points on the system. By permission of the authority enforcing this code (1) any individual ground connection may be omitted provided there are other good ground connections or (2) transformer or system grounding solely may be used.

It is recommended that such systems be grounded as provided herein, if the voltage to ground exceeds 150 volts, but does not exceed 300 volts.

d. Where transformers supply a common set of distribution mains, such fuses as are installed shall be so placed as not to leave any portion of the secondary system without ground protection after the fuses have opened.

903. Grounding Interior Wiring Systems

a. Direct-current interior wiring systems shall not be grounded either at individual services or elsewhere on the interior system.

b. Alternating-current interior wiring systems containing a conductor corresponding to a grounded conductor of the distribution system shall be grounded. Every lighting and application branch circuit shall have one wire continuously identified, grounded and connected to each lamp or appliance on the circuit, except that two-wire branches tapped from the outside wires of a 3-wire single phase circuit within the same premises will be permitted if no fuse is omitted and no single pole switches or sockets are used.

c. For alternating-current interior wiring systems, the conductor to be grounded shall be as follows:

(1) Single-phase, 2-wire: the identified conductor;

(2) Single-phase, 3-wire: the identified neutral conductor;

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(3) Multiphase systems having one wire common to all the others: the identified common conductor;

(4) Multiphase systems having one phase grounded: identified conductor.

(5) Multiphase systems in which one phase is used as in (2): the identified neutral conductor.

d. The grounding connection for an interior wiring system or for any circuit electrically connected to the service conductors shall be made on the supply side of the service switch before the wiring is put in use. For an interior system not electrically connected to exterior conductors, the grounding connection shall be made at the transformer, generator, or other source of supply or at a switchboard, and on the supply side of the first switch controlling the system. If one of the conductors is identified the grounding connection shall be made to the identified conductor, commonly known as "the white wire."

e. The grounded conductor of an interior wiring system shall be connected from one point only within the building to the grounding electrode or electrodes.

f. Electric furnace circuits need not be grounded.

904. Grounding Interior Conduit and Other Interior Wiring System Raceways of Metal

a. All metallic conduit, armored cable, metal raceway, metallic underfloor duct, electrical metallic tubing systems and other metallic raceways shall be grounded, whether the contained interior wiring system is grounded or ungrounded, unless in runs of less than 25 feet and free from metallic contact with the ground and from adjacent grounded metal and are guarded when within reach from grounded surfaces. Service conduit need not be grounded under the conditions given in paragraph g of section 404 of Article 4 of this code.

b. The grounding connection for such systems shall be made at a point as near as practicable to the source of supply, but the point of attachment shall be such that no run of conduit, cable and the like is grounded through a run of smaller size unless the provisions of paragraph k, section 907 of this article, are satisfied.

c. Where the service conduit or service-cable sheath is grounded in accordance with the foregoing, its grounding conductor shall be run from it directly to the ground, no portion of the service-switch box, or house conduit, being interposed in the grounding circuit. The following exceptions are permitted: Where the service-switch box or

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house conduit is grounded and is installed in dry, non-corrosive locations, the service-switch box may be interposed in the grounding circuit of the service conduit provided that bonding jumpers or ground clamps or lugs or devices approved for the purpose are used.

For special requirements in Hazardous Locations, see section 3204 and 3205 of Article 32 of this code.

d. Interior conduit and other interior wiring system raceways of metal, exposed metal of fixed current using equipment and control apparatus that are required to be grounded, the service conduit, service-cable sheath and service equipment may use the interior wiring system grounding conductor and its electrode for grounding when the connection is made on the supply side of the service switch and provided that the supply system is grounded at two or more locations not in the same building to a continuous metallic underground piping system, otherwise where grounded they shall each have a separate grounding conductor and where artificial grounds are used they shall have separate electrodes.

e. Where sections of conduit, armored cable, metal raceways and the like are required to be grounded, they shall be bonded together and grounded or each section or piece shall be grounded separately.

f. The point of attachment of the grounding conductors provided in accordance with this article shall be accessible if practicable.

905. Grounding Fixed Equipment

a. Exposed non-current carrying metal parts of fixed equipment such as the following, shall be grounded as provided in this and other sections of this code.

(1) Service equipment, as provided in 405-i.

(2) Generators operating in excess of 150 volts where accessible to other than qualified persons as provided in 1002-f.

(3) Fixed motors operating at a potential in excess of 150 volts where accessible to other than qualified persons as provided in 1003-1.

(4) Auto-transformer starters as provided in 1005-e.

(5) Switch and circuit-breaker enclosures with any wire over 150 volts to ground where accessible to other than qualified persons as provided in 1202-d.

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(6) Switchboard instrument cases as provided in 1302-g.

(7) Lighting fixtures as provided in 1403-a and b.

(8) Arc lamps on circuits in excess of 150 volts to ground as provided in 1502-b.

(9) Mercury-vapor lamps where within easy reach from grounded surfaces as provided in 1503-d.

(10) Stationary heating appliances above 150 volts to ground as provided in 1606-a.

(11) Motor frames, track and frame of electrical cranes as provided in 3008-a.

(12) Elevators as provided in 3104-a to d.

(13) Equipment in hazardous locations as provided in 3203-p, 3204-m and 3205-m.

(14) Equipment in garages as provided in 3308-a.

(15) Equipment in motion picture studios as provided in 3402-i.

(16) Signs and troughs for outline lighting, as provided in 3806-a.

(17) Equipment in theatres as provided in 3801-d.

(18) Vacuum and inert-gas systems as provided in 5002-e.

(19) Apparatus on systems of over 600 volts.

(20) Transformer cases except instrument transformers as provided in 5005-c.

(21) X-ray apparatus as provided in 5012-g.

b. Metal enclosures and covering for conductors, and separate grounding wires run in wire assemblies with the circuit conductors, are considered as suitable grounding conductors for protective grounding of fixed equipment when installed and used in compliance with the requirements of this article and Article 5 of this code.

c. A separate grounding conductor, if used for grounding fixed equipment, shall be installed as provided in section 907.

d. The point of attachment of the grounding conductor shall be accessible.

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906. Grounding Portable Equipment

a. The following exposed non-current carrying metal parts of portable equipment shall be grounded:

(1) Portable motors which operate at more than 150 volts to ground as provided in 1003-1.

It is recommended that the frames of portable motors which operate at less than 150 volts be grounded when this can be readily accomplished.

(2) Portable lamps or other portable current consuming devices in hazardous locations as provided in 3203-m and o, 3204-1 to n and 3205-1 and m.

b. Metal enclosures and coverings for conductors, and separate grounding wires run in wire assemblies with the circuit conductors, are considered as suitable grounding conductors for protective grounding of portable equipment when installed and used in compliance with the requirements of this article and Article 5 of this code.

c. A separate grounding conductor, if used for grounding portable equipment, shall be installed as provided in section 907 of this article.

d. The point of attachment of the grounding conductor shall be accessible.

907. Grounding Conductors

a. The conductor for grounding an interior wiring system shall be a copper wire or a wire of non-corrodible material of equivalent conductance, and shall be without joint or splice. For grounding conduit, equipment and the like, the conductor may be of copper or may be a rigid electrical conduit or pipe, except that under conditions favorable to corrosion, copper only shall be used. For grounding equipment, devices and the like, there may be used the metal enclosures of the wires which supply them or separate grounding wires run in wire assemblies with the circuit conductors.

b. When parts of the conduit system are used for grounding equipment, conduit, etc., on circuits operating with any conductor at more than 150 volts to ground, the electrical continuity of the conduit system shall be secured by one of the following methods:

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(1) Approved threaded fittings with joints made up tight.

(2) Approved threadless fittings with joints made up tight.

(3) Bonding jumpers with proper fittings.

(4) Two locknuts, one inside and one outside of boxes or cabinets.

For service entrance conduit, see paragraph c of section 904. For hazardous locations, see Article 32.

c. No automatic cutout or switch shall be placed in a grounding conductor for an interior wiring system unless the opening of the cutout or switch disconnects all sources of energy.

d. The installation of the grounding conductor for systems, when not consisting of or enclosed in metallic piping, and the insulating covering of the conductor shall comply with all requirements of this code applying to wires of the voltage of the circuit to which the grounding conductor is attached. When a grounding conductor of an interior wiring system with independent grounding conductor is installed in steel conduit or in armored cable, it shall be bonded to the conduit or armor at both ends, in which case a bare conductor may then be used within the pipe.

e. Approved ground clamps or other approved fittings shall be used and unless approved for general use without protection they shall be protected from ordinary mechanical injury by being placed where they are not liable to be damaged or by being enclosed in metal, wood or equivalent protective covering. Grounding wires smaller than No. 4, within seven feet from the floor, shall be protected from ordinary mechanical injury by being enclosed in metal, wood or equivalent protective covering. Lightning-arrester grounding wires shall be protected by non-magnetic material, unless the grounding conductor is electrically connected to both ends of the protective covering.

f. The path to ground provided by a system grounding conductor shall, in general, have current-carrying capacity sufficient to insure the continuity and continued effectiveness of the path under conditions of excess current caused by accidental grounding of any normally ungrounded conductor of the circuit or the system to which it is electrically connected.

g. The grounding conductor for a direct-current system shall have a current-carrying capacity not less than that of the largest feeder of the same system leaving the station. In no case shall the grounding conductor be smaller than No. 8.

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h. The grounding conductor for an alternating-current circuit or system shall have a current-carrying capacity not less than one-fifth that of the conductor to which it is attached. In no case shall the grounding conductor be smaller than No. 8.

i. The grounding conductor for a lightning arrester shall not be connected to an artificial ground electrode which is used for circuits or equipment and the like, but shall be kept at a distance of at least 20 feet where practicable. The grounding conductor shall have a current-carrying capacity sufficient to insure the continuity and continued effectiveness of the path to ground under conditions of excess current caused by or following the discharge of the arrester. No individual grounding conductor shall be smaller than No. 6.

j. The size of the wire or pipe used for grounding the service conduit shall be not less than that given in the following table:

Nominal Size of Conduit Service	Grounding Conductor If wire, No.	if Pipe, Size
¾-1	8	½ inch
1-¼-1-½	6 gauge	¾
2	4	1
2-½	2	1-¼
3	0	1
3-½-4	00	1
above 4	000	1

k. The size of the wire or of the pipe used for grounding interior conduit, armored cable, metal raceway, fixed equipment and the like, shall be not less than that given in the following table:

Capacity of Automatic Overload Protective Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size of Copper Wire (No.)	Nominal Size of Grounding Pipe (Inch)
30	14	½
60	10	¾
100	8	1
200	6	1-¼
400	4	1-½
600	2	2
800	0	2-½
1000	00	3
1200	000	3-½

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Where pipe is used as a grounding conductor, as in last column of above table, the connections thereto shall be made by means of an approved connector. Threaded connections are preferable, especially where the pipe or conduit is not provided with a conducting coating such as galvanizing.

This table does not apply to the grounding conductor when in non-metallic sheathed cable.

l. For grounding portable or pendent equipment, the conductors to which are protected by fuses or circuit-breakers not greater than 15 amperes, No. 18 copper wire may be used. For grounding portable equipment fused for more than 15 amperes, the above table shall be followed.

m. The grounding conductors for circuits, conduit, equipment, and the like shall not be connected to lightning rods.

n. Instruments, meters, or relays which operate with windings or working parts at 300 volts or more to ground shall have the cases and other exposed bare metal parts grounded unless isolated by elevation or protected by suitable insulating barriers or guards, except where inaccessible to other than qualified persons, in which case this requirement is made only if the voltage to ground exceeds 750. Where instruments, meters or relays are operated from current or potential instrument transformers on circuits of 300 volts or more to ground, having ungrounded secondary circuits and ungrounded primary circuits, the cases and other exposed bare metal parts shall be grounded. The grounding conductor for cases and for secondary circuits of instrument transformers shall be not smaller than No. 12.

For exception, see paragraph 9 of section 1302, of Article 13 of this code.

o. Secondaries of current and potential instrument transformers and the cases of instruments connected to such circuits shall, when grounded, have separate grounding conductors, and shall not be connected with a grounding conductor used for other circuits or for conduit, equipment and the like, except where a general ground bus is provided.

908. Grounding Connections

a. Where a non-conductive protective coating such as paint or enamel is used to protect the equipment, conduit-couplings and fittings, such coating shall be completely removed from threads and other surfaces in order to insure a good contact between ground clamp and equipment. Pipes and rods used as ground electrodes shall have clean metal surfaces, and shall not be covered with paint, enamel, or other poorly conducting materials.

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b. At supply stations, grounding conductors for circuits, equipment and lightning arresters shall be permanently and effectively connected to all available active, continuous, metallic underground piping systems between which no appreciable difference of potential normally exists; otherwise to one system only. Else where than at supply stations, the grounding conductor shall be connected to at least one such piping system, if available. (Gas piping shall be avoided wherever practicable, except as provided in paragraph e of this section.) Where underground metallic piping systems are not available, other grounds which will provide the desired permanence and conductance may be permitted.

c. The point of connection to the water piping system shall be located on the street side of the water meter or at a water pipe near the equipment to be grounded, in which case the connection with the piping system shall be made continuous and permanent, by bonding all parts of the piping system which are liable to become physically disconnected such as at meters and service unions, by means of a suitable shunt whose joints, current carrying capacity, and mechanical protection shall be not less than that required for the grounding conductor. Where practicable the point of connection shall be readily accessible.

d. The grounding conductor shall be attached to the pipe or rod (1) by means of an approved bolted clamp to which the conductor is soldered or otherwise connected in an approved manner or (2) by means of a pipe fitting, a plug or approved device screwed into the pipe or into the fitting, or (3) by other approved means.

e. Gas piping systems within buildings connected to continuous-metallic underground exterior systems may be used as a ground electrode but only when water piping is not available. Gas piping, however, may serve as the sole ground for small fixtures located at a considerable distance from water piping. Where gas piping on the house side of the meter is utilized for grounding small fixtures it shall be bonded to the water piping system at their points of entrance. If no water piping is available a bonding jumper around the gas meter should be used. Where grounding connection is made to gas piping, except for such small fixtures, it shall follow the same requirements as for water piping in paragraph c, of this section, except that the connection shall always be made on the street side of the meter. Gas piping need not be insulated from otherwise well-grounded fixtures.

f. Rails or other grounded conductors of electric railway circuits shall not be used as a ground for other than railway lightning arresters and railway equipment, conduit, armored cable, metal raceway, and the like, when other effective grounds are available, and in no case shall such rails or other grounded conductors of railway circuits be used for grounding electrode for interior wiring systems other than those supplied from the railway circuit itself.

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NATIONAL ELECTRICAL SAFETY CODE

The fourth edition of the National Electrical Safety Code issued by U. S. Bureau of Standards, was approved December 16, 1927, as an American Standard. Section 9 of this code contains rules covering protective grounding of circuits, equipments, and lightning arresters for stations, lines, and utilization equipment. The rules in this section do not attempt to tell what equipment is to be grounded, but go into considerable detail as to the methods which should be used in making an efficient ground connection. Thus they are of great value to one who wants not only to carry out grounding regulations but also to do it in an effective manner. The regulations follow:

90. Scope of the Rules

The following rules apply to the grounding of all lightning arresters, except those on communication circuits, and of all circuits, equipment, or wire runways when the grounding is intended to be a permanent and effective protective measure.

They do not apply to the grounded return of electric railways, nor to the grounding of lightning protection wires which are independent of electric circuits or equipment.

These rules do not require that grounding shall be done, but cover the methods for protective grounding. The rules requiring grounding, in accordance with the methods specified below, are included under the various parts of this code.

Other methods of construction and installation than those specified in the rules may be used as experiments to obtain information if done where supervision can be given by the proper administrative authority.

91. Application of the Rules

(a) Waiving rules. - The rules are intended to apply to all installations except as modified or waived by the proper administrative authority or its authorized agents. They are intended to be so modified or waived in particular cases wherever any rules are shown for any reason to be impracticable, such as by involving expense not justified by the protection secured; provided equivalent or safer construction is secured in other ways.

(b) Application. - The intent of the rules will be realized (1) by applying the rules in full to all new installations, reconstructions, and extensions, except where any rule is shown to be impracticable for special reasons or where the advantage of construction in compliance with the rules, providing the existing construction is reasonably safe; (2) by placing grounds on existing installations or bringing present grounds into compliance with the rules, except where the expense involved is not justifiable.

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The time allowed for bringing existing installations into compliance with the rules will be determined by the proper administrative authority.

(c) Temporary installations. - It will sometimes be necessary to modify or waive certain of the rules in case of temporary installations which are shortly to be dismantled or reconstructed.

(d) Emergency. - In cases of emergency or pending decision of the administrator the person responsible for the installation may decide as to modification or waiver of any rule, subject to review by proper authority.

92. Point of Attachment of Grounding Conductor

(a) Direct-current distribution systems. - In three-wire direct-current systems the ground connections shall be made on the neutral at one or more supply stations.

In two-wire direct-current systems the ground connection shall be made at one station only.

No ground connection shall be made at individual services or within the building served. In two-wire systems the grounded side of the circuit shall be insulated from ground except at the station ground connection.

(b) Alternating-current distribution systems. - In alternating-current systems the ground connection shall be made at the building service or near the transformer (or transformers) either by direct ground connection (through water-piping system or artificial ground, see rule 94) or by the use of a system ground wire to which are connected the grounded conductors of many secondary mains and which is itself effectually grounded at intervals that will fulfill, for any secondary utilizing the system ground wire, the resistance and current-carrying requirements of rule 96.

When the secondaries of transformers are supplying a common set of mains, fuses, if installed, shall be located only at such points as not to cause the loss of the ground connections after any fuses in the transformer circuits or mains have been blown.

Alternating-current secondary circuits supplied from a transformer outside the building shall not be grounded inside buildings except at the service entrance.

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In single-phase, three-wire systems the ground shall be on the neutral conductor. In single-phase two-wire systems the ground may be made on either conductor. In two-wire single-phase and in two or three phase systems the ground shall be made at that point of the system which brings about the lowest voltage from ground or unguarded current-carrying parts of connected devices. Where one phase of a two or three phase system is used for lighting, that phase should be grounded and at the neutral conductor, if one is used.

In the absence of direct grounds at all building services, ground connections shall be made to the grounded neutral or other grounded conductor of a secondary system supplying more than one utilization equipment, at intervals that will fulfill the resistance requirements of rule 96 (a).

(c) Current in grounding conductor. - Grounds shall be so arranged that under normal conditions of service there will be no objectionable flow of current over the grounding conductor.

Where the objectionable flow of current over a grounding conductor is due to the use of multiple grounds, one or more of such grounds shall be abandoned or the location changed.

(d) Equipment and wire runways. - For conduit, armored cable, metal raceways, generators, motors, transformers, and other equipment, the point at which the grounding conductor is attached shall, if practicable be readily accessible.

No separate grounding conductor shall be required for non-current-carrying parts of equipment if grounded through the conduit, cable sheath, or metal raceway system of the building by means of standard lock nuts and bushings or by a separate bond between the equipment and the conduit, armored cable, or metal raceway system.

For conduit, armored cable, or metal raceways the ground connection shall be as near as practicable to the point where the conductors in the conduit system concerned receive their supply.

(e) Service conduit. - When the service conduit is grounded, its grounding wire shall be run directly from it to the ground connection. The interior conduit, armored cable, or metal raceways, if well bonded to the service conduit, grounded as provided in this rule, needs no additional ground connection.

93. Grounding Conductor

(a) Material and continuity. - In all cases the grounding conductor shall be of copper or of other metal which will not corrode excessively under the existing conditions and, if practicable, shall be without joint or splice. If joints are unavoidable they shall be so made and maintained as to conform to the resistance requirements of rule 96.

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In no case shall a fuse or automatic circuit-breaker be inserted in the grounding conductor or connection except in a ground connection from equipment where its operation will result in the automatic disconnection from all sources of energy of the circuit leads connected to equipment so grounded; no switch shall be so inserted except in plain sight, provided with distinctive marking and effectively isolated from unqualified persons. (See also rule 92 (b), par. 2.)

For lightning arresters and ground detectors the grounding conductor shall be as short and straight as practicable and free from sharp bends.

(b) Size and capacity. - The conductor or conductors for grounding circuits shall have a combined current capacity sufficient to insure the continuity and continued effectiveness of the ground connection under conditions of excess current caused by accidental grounding of any normally ungrounded conductor of the circuit. No individual grounding conductor for electrical circuits shall have current capacity less than that of a No. 8 (0.128 inch)copper wire.

The grounding conductor for a direct-current system shall have a current capacity not smaller than the largest feeder of the same system leaving the station.

The grounding conductor for alternating-current systems shall have a current capacity not less than one-fifth that of the conductor to which it is attached, except that it need not be larger than No. 0 (0.325 inch) copper.

For lightning arresters the grounding conductor or conductors shall have a current capacity sufficient to insure continuity and continued effectiveness of the ground connection under conditions of excess current caused by or following discharge of the arrester. No individual grounding conductor shall have less conductance than No. 6 (0.162 inch) copper wire.

For noncurrent-carrying parts of electrical equipment the conductance of a grounding conductor shall be not less than that provided by a copper wire of the size indicated in the following table. When there is no fuse or automatic circuit-breaker protecting the equipment, the size of the grounding conductor will be determined by the design and operating conditions of the circuit.

Rating of fuse or circuit-breaker which protects equipment or conductors	Size of grounding wire		Nominal size of grounding pipe
	A.W.G.	Inch	Inch
Not more than 100 amperes	10	0.102	$\frac{1}{2}$
More than 100, but not more than 200 amps.	6	.162	$\frac{3}{4}$
More than 200, but not more than 500 amps.	4	.204	$\frac{3}{4}$
More than 500 amperes	2	.258	1

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In portable cord to portable equipment protected by fuses not greater than 15 amperes capacity, a No. 18 (0.040 inch) grounding wire may be used.

Grounding wires for conduit, armored-cable, or metal-raceway systems shall have a conductance at least equivalent to No. 10 (0.102 inch) copper where largest wire contained is not larger than No. 0 (0.325 inch), and need not be larger than No. 4 (0.204 inch) where the largest wire contained is larger than No. 0; and for service conduit the grounding wire shall have a conductance not less than that of No. 8 (0.128 inch) copper wire.

(c) Mechanical protection and guarding against contact. - Where exposed to mechanical injury the grounding conductor shall be protected by substantial conduit or other guard. Guards for lightning-arrester grounding conductors shall be of nonmagnetic material unless the grounding conductor is electrically connected to both ends of the guard.

If the resistance of the ground connection is in excess of three ohms, the grounding conductor, except in rural districts, shall be protected and guarded by being inclosed in insulating conduit or molding to protect persons from injury by coming in contact with it.

Note. - Such a high resistance may exist where artificial grounds are necessarily permitted in lieu of the preferable grounds to buried metallic water-piping systems.

Mechanical protection and insulating guards should extent for a distance of not less than 8 feet above any ground, platform, or floor from which grounding conductors are accessible to the public.

Note. - Insulating mechanical protection is advixable for single arrester grounds, even when the connection is made to a water-piping system, and has therefore a low resistance, since a single connection is liable to be accidentally broken.

Even where ground connections have a resistance not exceeding that specified in rule 96 and no guard is therefore provided (or as an additional protection to persons even where guards are used) artificial grounds may be arranged to minimize the potential gradient along the surface of the earth by use of radial connecting wires underneath the earth surface or by other suitable means.

A grounding conductor for a circuit shall be guarded as required for current-carrying conductors of the circuit.

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Exceptions. - (1) A grounding conductor for a circuit having multiple grounds, where such conductor is entirely outside buildings and has strength and current capacity not less than No. 6 (0.162 inch) copper wire.

(2) In stations substantial bare ground busses may be used.

(d) Underground. - Wires used for grounding conductors if laid underground, shall, unless otherwise mechanically protected, be laid slack to prevent their being readily broken and shall have joints carefully painted or otherwise protected against corrosion.

94. Ground Connections

The ground connections shall be permanent and effective, and be made as indicated below, but always to water-piping systems, if available.

(a) Piping systems. - For circuits, equipment, and arresters at supply stations, connections shall be made to all available active metallic underground water-piping systems between which no appreciable difference of potential normally exists, if the pipe is of sufficient capacity, and to one such system if appreciable differences of potential do exist between them. At other places connections shall be made to at least one such system, if available. Gas piping should not be used for grounding circuits.

Note. - The protective grounding of electrical circuits and equipment to water-pipe systems in accordance with these rules should always be permitted, since such grounding offers the most effective protection to life and property and is not injurious to the piping systems.

Ground connections from circuits should not be made to jointed piping within buildings except water piping.

(b) Alternate methods. - Where underground metallic piping systems are not available, other methods which will secure the desired permanence and conductance may be permitted. In many cases metal well casings, local metal drain-pipes, and similar buried metal structures of considerable extent will be available and may be used in lieu of extended buried water-piping systems.

In some cases ground connection may be made to the steel frame of a building containing the grounded circuits or equipment, to which frames of machines and other non-current-carrying surfaces should also then be connected. In such cases the building frame should be itself well grounded by effective connection to the ground. This may require artificial grounding for steel-frame buildings supported on masonry or concrete footings.

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(c) Artificial grounds. - When resort must be had to artificial grounds, their number should be determined by the following requirements:

(1) Not more than one such ground is required for lightning arresters, except where for large current capacity.

(2) At least two grounds are required for low-voltage alternating-current distribution circuits at transformers or elsewhere, except as specified in (3).

(3) Where no part of the circuit or equipment protected can be reached by persons while they are standing on the ground or damp floors, or by persons while touching any metallic piping to which the grounding conductor is not effectively connected, a single artificial ground may be used even if its resistance exceeds that specified in rule 96. In such cases it is desirable to provide guards for the grounding conductor in accordance with rule 93 (c) wherever it is otherwise accessible, or to provide insulating mats or platforms so located that persons can not readily touch the grounding conductors without standing on such mats or platforms.

(d) Grounds to railway returns. - Protective ground connections should not be made to railway negative-return circuits when other effective means of grounding are available, except ground connections from electric railway lightning arresters.

When ground connections are of necessity made to the grounded track return of electric railways, they shall be made in such a manner as not to afford a metallic connection (as indirectly through a grounded neutral with multiple grounds) between the railway return and the other grounded conducting bodies (such as buried piping and cable sheaths).

Note. - This rule does not prohibit the making of drainage connections (which are not protective grounds) between piping systems and railway negative-return circuits for the prevention of electrolysis.

Multiple protective ground connections from other circuits to railway returns should be avoided, and where multiple artificial grounds are made on such other circuits near such railway returns, they should be so arranged as to prevent the flow of any considerable current in and between such connections, which flow would reduce their effectiveness.

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95. Method

(a) Piping. - Ground connections to metallic-piping systems shall be made (except as permitted below) on the street side of water meters, which might interrupt the continuity of the underground metallic-pipe systems, but connections may be made immediately inside building walls to secure accessibility for inspection and test. When water meters are located outside buildings or in concrete pits within buildings where piping connections are embedded in concrete flooring, the ground connection may be made on the building side of the meters.

Ground connections for equipment, conduit, armored cable or metal raceways, and the like, or as a multiple ground for alternating-current secondaries, may be made to the water-piping system at a point near the part to be protected, provided there are no insulating joints or fittings in the pipe to prevent a good ground. In such cases care shall be taken to electrically connect all parts of the piping system liable to create a hazard (if they become alive) and the pipe system shall be shunted where necessary around meters, etc., in order to keep the connection with the underground piping system continuous.

Gas-piping systems within buildings should not be used for purposes of this rule, except that gas piping need not be insulated from otherwise well-grounded electrical fixtures, and where the making of another ground connection for a fixture would involve a long run and the fixture is, therefore, of course, not within reach of plumbing or plumbing fixtures, the gas piping may for small fixtures be utilized as the sole ground connection. Where gas piping is so used it must be bonded to the water-piping system at the point of entrance of water piping.

(b) Ground clamps. - The ground connection to metallic-piping systems shall be made by means of an approved clamp firmly bolted to the pipe after all rust and scale have been removed, or by means of a brass plug which has been tightly screwed into a pipe fitting or, where the pipe is of sufficient thickness, screwed into a hole in the pipe itself, or by other equivalent means.

The grounding conductor shall be attached to the clamp or to the plug by means of solder or by an approved solderless connector. The point of connection shall be as readily accessible as possible, and the position should be recorded.

Note. - With bell-and-spigot-joint pipe it may be necessary to connect to several lengths where circuits or equipment of large current capacity are being grounded.

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(c) Contact surfaces. - If conduit, couplings, or fittings having protective coating of nonconducting material, such as enamel, are used, such coating shall be thoroughly removed from threads of both couplings and conduit and such surfaces of fittings where the conduit or ground clamp is secured, in order to obtain the requisite good connection. Grounded pipes shall be free from rust, scale, etc., at the place of attachment of ground clamp.

The armor of conduits, cables, metal raceways, and gas pipes shall be securely fastened in outlet boxes, junction boxes, and cabinets, so as to secure good electrical connection.

In ice houses, packing plants, etc., where a great deal of moisture is present and where conduits are attached to metal cabinets, cut-out, pull or junction boxes, compensators, etc., by means of standard lock nuts and bushings, these conduits should be bonded together with approved ground clamps.

(d) Artificial grounds. - Artificial grounds should be located where practicable below permanent moisture level or, failing in this, at least 6 feet deep. Each ground should present not less than 2 square feet of surface to exterior soil. Areas where ground water level is close to the surface should be used when available.

Where facilities are not available for determining the resistance of the ground connection (see rule 96), the exposed surface should be not less than 4 square feet.

Where copper ground plates are used, they should be at least 0.06 inch thick. When driven pipes are used, they should be of galvanized iron and not smaller than three-fourths inch internal diameter, and when cast-iron plates are used they should be at least 0.25 inch thick.

96. Ground Resistance

(a) Limits. - The combined resistances of the grounding wire and the connection with the ground shall not exceed 3 ohms for water-pipe connections nor 25 ohms for artificial (buried or driven) grounds. Where it is impracticable to obtain with one ground artificial-ground resistance as low as 25 ohms, this requirement shall be waived, and two artificial grounds, at least 6 feet apart and with combined area of not less than 4 square feet, shall be provided.

(b) Checking. - The resistance of station grounds should be checked when made.

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Note. - With artificial grounds this check may be made by measuring the voltage between the grounded point of the circuit, or the grounded frame of the equipment, or the grounded point of the lightning arrester, and an auxiliary metal reference rod or pipe driven into the ground, while a measured current is flowing through the ground connection and any exposed metal piping or other artificial ground not less than 20 feet distant.

If the station ground is to water piping, the check may be made with current flowing through the water piping and some independent piping system or artificial ground not less than 20 feet distant.

The auxiliary rod or pipe should be at least 10 feet from any artificial ground or piping systems through which the measured current is made to flow.

All ground connections shall be inspected periodically.

Ground connections on distribution circuits should, when installed, be tested for resistance unless multiple grounding to water-piping systems is used.

97. Separate Grounding Conductors and Grounds

(a) Grounding conductors. - Grounding conductors from equipment and circuits of each of the following classes, when required by these rules, shall be run separately to the ground (or to a sufficiently heavy grounding bus or system ground cable which is well connected to ground at more than one place):

(1) Lightning arresters.

(2) Secondaries connected to low-voltage lighting or power circuits.

(3) Secondaries of current and potential instrument transformers and cases of instruments on these secondaries.

(4) Frames of direct-current railway equipment and of equipment operating in excess of 750 volts.

(5) Frames of utilization equipment or wire runways other than covered by item (4), except that if a secondary distribution system has multiple grounds to water piping, service conduits may utilize the same grounding conductors.

(6) Lightning rods.

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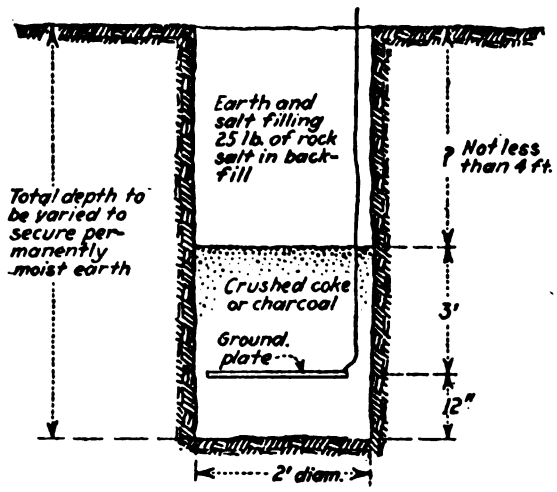
Earth and salt filling 25 lb. of rock salt in back-fill
Not less than 4 ft.
Total depth to be varied to secure permanently moist earth
Crushed coke or charcoal
Ground plate
3'
12"
2" diam.

Figure 1.- Grounding to buried plate

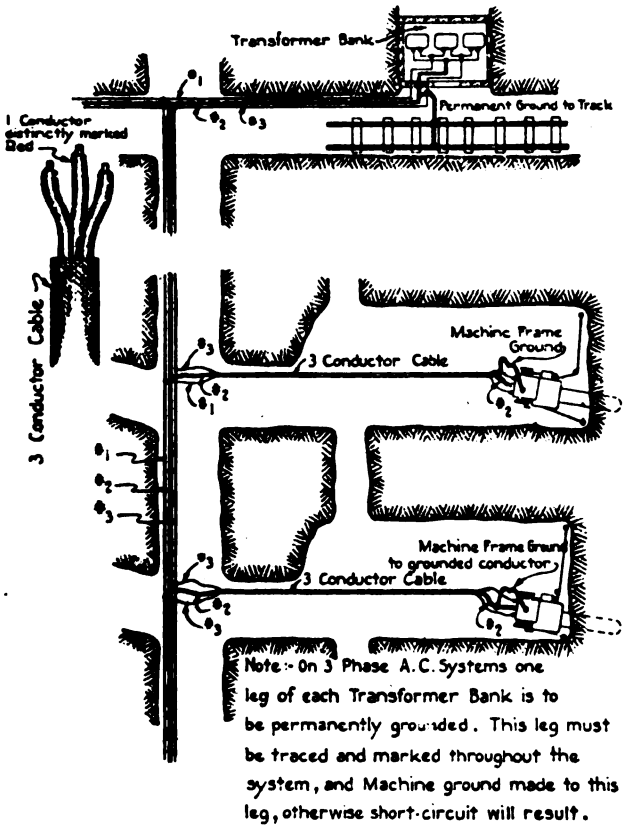
Transformer Bank
Permanent Ground to Track
1 Conductor distinctly marked Red
3 Conductor Cable
Machine Frame Ground
3 Conductor Cable
Machine Frame Ground to grounded conductor
3 Conductor Cable
Note:- On 3 Phase A.C. Systems one leg of each Transformer Bank is to be permanently grounded. This leg must be traced and marked throughout the system, and Machine ground made to this leg, otherwise short-circuit will result.

Figure 2.- Grounding for A. C. mining machine frames

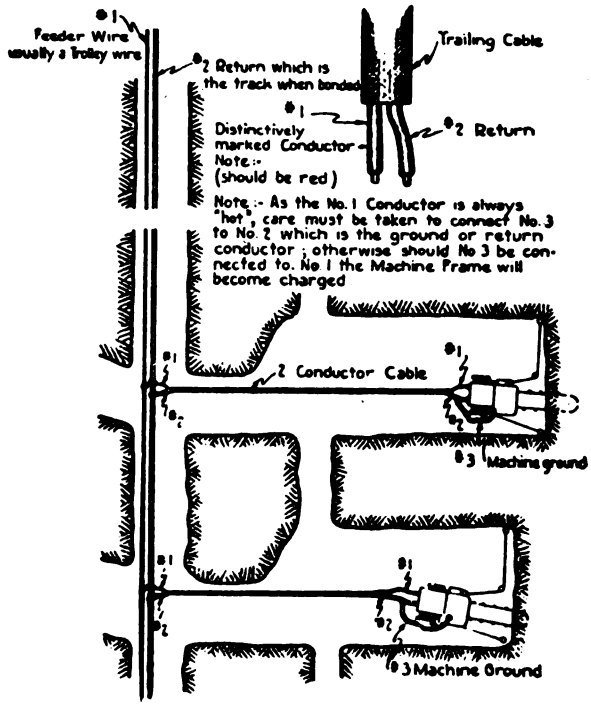
Feeder Wire usually a Trolley wire
Trailing Cable
2 Return which is the track when bonded
Distinctively marked Conductor
2 Return
Note:- (should be red)
Note:- As the No. 1 Conductor is always "hot", care must be taken to connect No. 3 to No. 2 which is the ground or return conductor; otherwise should No 3 be connected to. No 1 the Machine Frame will become charged
2 Conductor Cable
3 Machine ground
3 Machine Ground

Figure 3.- Grounding for D. C. mining machine frames

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(b) Arrester grounds. - Lightning-arrester ground connections shall not be made to the same artificial ground (driven pipes or buried plates) as circuits or equipment, but should be well spaced and, where practicable, at least 20 feet from other artificial grounds.

GROUNDING AS PRACTICED BY THE UNION PACIFIC COAL CO.

As far as is known, the Union Pacific Coal Co. has the most complete safety code that has been promulgated by a mining company. In these standards there are some valuable rules covering grounding of circuits and equipment. With the consent of Eugene McAuliffe, president of the company, most of the material on grounding has been abstracted for the benefit of those having similar problems. The abstract follows:

Grounding

1. The frames, casings or inclosures of all stationary electrical apparatus such as motors, M. G. sets, rotary converters, transformers, starting and control apparatus, oil switches, cable sheaths, conveyors, hoists or other equipment that may become accidentally charged with electric current shall be grounded.

(By grounding is meant making a permanent connection to the general mass of earth in such a manner as will insure at all times an immediate discharge of electrical energy to the earth without danger.)

A thorough inspection of all ground connections will be made every thirty days.

Size

2. Ground wires shall be not smaller than No. 4 B & S gage and need not be larger than 00 B & S gauge.

Ground Terminals

3. Ground-wire connections to the apparatus shall be made by means of terminals soldered to the ground wire and securely bolted to the apparatus from which its removal will be unnecessary for inspection and repair.

Connections to Ground

4. All ground connections shall be made to pipe lines, track, or to buried ground plates or pipes which shall be in contact with permanently moist earth. (See figure 1.) These connections to be mechanically secured and soldered or welded.

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Approval

5. All ground connections shall be approved by the local chief electrician, and in case any doubt exists as to the reliability of ground connections as designated in the foregoing paragraph, he shall withhold approval until sufficient ground connections have been made to serve the purpose for which intended.

Ground Wire in Pipe

6. Ground wires should be straight and as short as possible, and where necessary to run in conduit, the ground wire shall be electrically bonded thereto.

Stranded Ground Wire

7. Solid wire may be used as a ground conductor, excepting that stranded conductor shall be used to ground apparatus subject to movement or excessive vibration.

Continuity

8. Ground wires shall be installed in such a way that they may be inspected for continuity and be protected from mechanical injury.

Mining Machine Grounds

9. For method of grounding a.-c. and d.-c. mining machines see Figures 2 and 3.

10. Transformer cases, oil switches, and supporting frames shall be effectively grounded.

Transformer Grounding

11. The secondaries of one transformer of each 3-phase bank shall be grounded at the point which brings about the lowest voltage from ground to live conductor.

12. Single-phase lighting transformers shall have the case and one side of the secondary grounded.

Duplicate Grounds

13. All 2200-volt motors driving M. G. sets, hoists, fans, or general purpose motors shall be provided with duplicate ground connections. Ground connections leading in different routes are preferred. Iron conduit, although grounded, connecting the motors will not be considered as constituting a ground conductor.

Permanent Grounds

Transformer cases should be grounded in such a manner that the earth contact is not disturbed during ordinary inspection and repair work. If the midpoint of a transformer secondary winding is not accessible, one secondary line should be grounded.

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Protecting an Open-Delta and Single-Phase Connection

A - The secondary circuit may be grounded either at the midpoint of a transformer winding or by making an earth connection to one of the line wires. In all instances the casings of the transformers should always be grounded.
B - This arrangement is usual for lighting transformers, but in all instances the tank should be grounded and also the midpoint of the secondary winding or a line wire.

Rotary Converter Grounds

14. Transformer secondaries supplying rotary converters shall not be grounded.

Arrester Grounds

15. Lightning arresters shall have individual ground connections.

Instrument Grounds

16. The cases of all instruments, relays, and meters shall be grounded with No. 12 B & S gage copper wire. Secondary circuits of potential and current transformers shall be grounded with a conductor not smaller than the conductor of the secondary circuit.

GROUNDING REGULATIONS FOR BITUMINOUS MINES IN PENNSYLVANIA

The Pennsylvania Bituminous Mine Law has rather complete safety requirements covering the installation of electrical equipment, but does not give detailed instruction for grounding. The law as it stands, especially most of the items referring to the use of electricity, was prepared in 1911, and naturally after a period of 19 years some need for improvement in regulation might be expected. The direct references dealing with grounding follow:

Grounding

3. All metallic coverings, armoring of cables, other than trailing cables, and where installed underground, the frames and bed-plates of generators, transformers, and motors, other than low voltage portable motors, shall be efficiently grounded, as shall also the neutral wire of three wire continuous current systems.

Protection of Machine Terminals

26. All terminals on machines over medium voltage underground shall be protected with insulating covers or with metal covers connected to earth.

Power and Light Circuits

30. All underground cables and wires, other than trailing cables, unless provided with grounded metallic covering, shall be supported by means of efficient insulators. The conductor connecting lamp to the power supply shall in all cases be insulated.

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Lighting Circuits

44. Wires for all lighting circuits shall be covered with an insulation adequate for the voltage of the circuit, and strung on porcelain or glass insulators, unless they are encased in pipes or other metallic covering. If separate uncased wires are used they shall be kept at least three inches apart, except where they enter the fittings. If metallic casings are used they shall be grounded efficiently.

Insulation and Coverings

47. Where lead-covered or armored cable is used, the lead or armor shall be electrically continuous throughout and shall be efficiently grounded.

GROUNDING REQUIREMENTS FOR UTAH COAL MINES

The Industrial Commission of Utah has issued "Safety Orders" effective September 1, 1920, in which requirements for grounding equipment and circuits in coal mines are listed. This commission has powers delegated to it similar to those given mine inspection departments in other States. However, as the commission can change the orders from time to time, their rulings are somewhat more flexible than those in most States governed by fixed safety codes which can be modified only by an act of the State legislature. Utah's grounding requirements follow:

General Coal-Mine Safety Orders

Issued By The Industrial Commission of Utah

Grounding

Section 77. (a) On low voltage circuits one conductor of each circuit shall be efficiently grounded at the transformer and such ground connection shall be separate and distinct from all other ground connections. The frames and bedplates of permanently installed generators, motors and transformers shall also be grounded.

(b) On medium voltage circuits the frames and bedplates of generators, motors and transformers; the metal enclosing cases and supports of switches, fuses, relays, meters and other electrical devices; and all metal coverings of wires and cables shall be efficiently grounded.

(c) On high voltage circuits the frames, bedplates, and other supports of generators, motors, transformers, switches, and all other electrical devices shall be efficiently grounded. All high voltage wires and cables installed underground shall be enclosed in a continuous metallic sheath surrounding all conductors of a circuit and effectively grounded at proper intervals. All live high voltage parts, connections and terminals, of switches, fuses, relays, meters and other electrical devices shall be completely enclosed (where practicable) in metal cases efficiently grounded.

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Where it is impracticable to so enclose high voltage devices they shall be so located or fenced in that they are inaccessible to unauthorized employees.

(d) On extra high voltage circuits the same orders shall apply as on high voltage circuits except that for surface installations open overhead wiring may be installed subject to rules governing the same.

(e) For any voltage circuit the ground connections for carrying the discharge from lightning arresters shall be installed at a safe distance from all other ground connections.

REFERENCE TO GROUNDING IN TECHNICAL PAPER 402

A set of safety rules sponsored by the U. S. Bureau of Mines and the American Mining Congress was approved as American Standard by the American Engineering Standards Committee in 1926. In these rules are found references to grounding, which are as follows:

Grounded Circuit. - The term "grounded circuit" means a circuit that is permanently grounded at one or more points.

Grounding. - The term "grounding" as applied to any object used in connection with a permanently grounded electric system means connecting such object to the earth in such a way that a path of low resistance and of adequate carrying capacity is provided between the object and the permanently grounded point of the system. A connection to a thoroughly bonded rail is an example of a good ground connection.

The term "grounding" as applied to any object used in connection with an electric system that is not provided with a permanent ground means making a connection to the general mass of earth in such a manner as will insure at all times an immediate discharge of electrical energy without danger.

Ground Return. - The term "ground return" means that part of a circuit which is the earth, or metallic conductors intimately associated with the earth, and which is practically at earth potential at all points.

14. Grounding of Machine Frames. - All metallic frames, casing, and coverings of stationary equipment that may become alive shall be permanently grounded. Portable machines other than locomotives, whose frames are not in intimate contact with the earth, shall have their frames grounded.

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15. Grounding of Metallic Sheaths. - All metallic sheaths or armors or cables shall be electrically continuous throughout and shall be effectively grounded. Weatherproof varnished cloth, rubber, or similar insulation, unless inclosed in a metallic sheath or armor, or both, when used underground will not be considered as a protection against shock.

29. Fan Circuits, Lightning Protection for. - If the line supplying power is exposed to the influence of lightning, lightning arresters with an efficient ground and choke coils shall be placed near the point where the wires enter the fan house.

42. Transformer Stations, Wiring of. - All wiring within transformer stations that is not installed in steel conduit shall be suitably supported on noncombustible framework. The supporting framework if of metal shall be grounded.

43. Construction and Installation. - . . . All switchboard mountings, instrument transformers, and meter casings shall be grounded. . . .

50. Motor, Control. - The motors and controlling appliances of portable pumps, hoists, and similar portable apparatus shall be securely mounted. Frames of portable motors and their controlling appliances shall have a common ground, preferable the base of the machine which the motor or motors operate. All wiring between motors and their controlling appliances shall be done in an approved manner.

77. Installation.- (c) All underground power conductors transmitting current at voltage exceeding 600 shall have grounded metallic coverings and shall be installed in approved manner, with special reference to the conditions under which they are surrounded.

91. Bore Holes, Installation of Circuits in. - Telephone or signal wires shall not be installed in the same bore hole with power wires unless either the signal or the power conductors in the bore hole are incased in metallic coverings that are effectively grounded.

101. Shot-Firing Circuits (outside firing). - (b) The following switches shall be installed in the shot-firing circuit; No. 1, a locked firing switch in the shot-firer's cabin; No. 2, a locked switch in the power house; No. 3, a 5-foot lightning gap (disconnecting switch) at the foot of the shaft or slope or at the drift entrance, which switch shall be arranged for grounding the incoming circuit when not in service; No. 4, a locked switch at the entrance to each heading or side entry; No. 5, a switch at the mouth of each working place.

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PRACTICE IN BRITISH COAL MINES

The following rules relating to earthing (grounding) in British coal mines have been abstracted from the "Coal Mines Act, 1911" entitled "General Rules as to the Installation and Use of Electricity with Explanatory Memorandum." The underlined sentences are the rules. The additional matter is explanatory and helps to interpret the intent of the rules. The abstracted matter follows:

Insulated and Earthed Systems

(124.) (c.) Every part of a system shall be kept efficiently insulated from earth, except that (i.) the neutral point of a polyphase system may be earthed at one point only; (ii.) the mid-voltage point of any system, other than a concentric system, may be earthed at one point only; and (iii.) the outer conductor of a concentric system shall be earthed. Where any point of a system is earthed it shall be earthed by connection to an earthing system at the surface of the mine.

Alternatives are permitted in the matter of earthing the system except in the case of a concentric system.

The advantage that is claimed sometimes for an insulated system that there is less risk of shock is not supported by the evidence of statistics.

On a high pressure system the capacity current to earth is dangerous while on medium pressure systems the leakage indicating instrument may provide a return path through earth.

In an installation of any magnitude the general distributed leakage will, so far as risk of shock is concerned, put the plant on all fours with an earthed system.

An objection is sometimes made that with an earthed system a defect of insulation entails a shut-down, but if there is a fault on the system the part affected ought to be isolated forthwith to comply with Regulation 131 (c), and moreover, if selective automatic protection is applied, the shut-down can generally be confined to the faulty circuit.

Where transformers are used, unless the lower pressure system is earthed, the insulation may be subjected to dangerous stresses if surges occur in the higher pressure system.

If the low-pressure winding of a step-down transformer is not earthed the conductivity of the metallic covering of the cable which supplies the high-pressure winding may not have the necessary 50 per cent conductivity which is required by Regulation 125 (b) with respect to the conductors of the low-pressure circuit.

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If, however, the neutral or mid-voltage point of the low pressure system is earthed, then that system may be regarded as being complete and self-contained.

It is a serious disadvantage of an insulated system that selective leakage protection, as distinct from the use of a mere leakage indicating instrument can not be applied effectively.

This disadvantage is shared also by the earthed concentric system. The larger Electric Power Supply Undertakings operate with an earthed neutral point on their 3-phase systems.

There is no objection to the use of a current limiting resistance between the neutral point of the live system and earth, provided the current is not restricted thereby below the value required to operate the circuit-breakers.

Such a resistance, however, will rarely be necessary except for large units of plant.

To earth the neutral point through a small fuse, which is sometimes shunted by a lamp, is objectionable from the point of view of safety, for the effective earth connection is removed, by the blowing of the fuse, at the moment when it is most urgently required to ensure the automatic cutting off of a faulty section.

As the outer conductor of a concentric system must be earthed, whereas the neutral point, or mid-voltage point, only of a 2-wire system may be earthed, it is obviously contrary to the Regulation to mix two-wire and concentric systems.

Earthing of Apparatus

(125.) - (a.) All metallic sheaths, coverings, handles, joint-boxes, switchgear frames, instrument covers, switch and fuse covers and boxes, and all lampholders, unless efficiently protected by an earthed or insulating covering made of fire-resisting material, and the frames and bedplates of generators, transformers, and motors (including portable motors), shall be earthed by connection to an earthing system at the surface of the mine.

This rule shall not apply (except in the case of portable apparatus) to any system in which the pressure does not exceed low pressure direct current or 125 volts alternating current.

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Although earthing is not compulsory, except in the case of portable apparatus where the pressure does not exceed the prescribed limits, it is nevertheless desirable where the pressure exceeds 50 volts alternating or 100 volts direct current, if the surroundings are such as to provide a conducting path of low resistance to earth.

With regard to the earthing system at the surface of the mine, this should be designed so that the resistance of the earth connection may be tested periodically without interrupting the circuit between earth and apparatus.

At least two separate earth connections should be provided, and a permanent earth test panel on the main switchboard will be found a great convenience.

The point of connection between earth conductor and earth plate should be open to inspection.

If buried or otherwise hidden corrosion may proceed undetected until some accident occurs.

Regarding the earthing of isolated motors in use above ground, the Regulation does not specifically prohibit the use of more than one earthing system at the surface of the mine.

If local earth plates are relied upon, it is even more important that their effectiveness shall be proved by periodical tests.

A continuous earthing conductor is preferable, so that all apparatus may be earthed to the main earthing system.

With regard to portable lamps the lampholder itself, as distinct from the guard or other metal work, need not be earthed provided it is effectively shrouded with fireproof insulating material and is not in electrical contact with any other metal part of the fitting.

All pendant lampholders and especially pendant switch lampholders, if they comprise exposed metal parts, should be earthed, even on systems falling within the exemption, if the floor or surroundings are of a conducting nature.

For such places, however, it is better to use lampholders encased in insulating material.

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Earthing Conductor

(Note. - Reg. 125 (b), here following, has been amended for application above ground by the addition of the clause in brackets at the end of the Regulation.)

(125.) - (b.) Where the cables are provided with a metallic covering constructed and installed in accordance with Regulation 129 (e) such metallic covering may be used as a means of connection to the earthing system. All the conductors of an earthing system shall have a conductivity at all parts and at all joints at least equal to 50 per cent of that of the largest conductor used solely to supply the apparatus a part of which it is desired to earth. Provided that no conductor of an earthing system shall have a cross-sectional area of less than .022 of a square inch.

(Except that in the case of a portable lamp or other portable apparatus of small current capacity, connected to the system by means of a flexible cable complying with Regulation (130), the cross-sectional area of the earthing conductor in the flexible cable shall not be required to be greater than the cross-sectional area of either of the live conductors in the same flexible cable.)

The acceptability of the metallic covering of a cable as the earthing conductor is subject to the condition that the cable shall comply with the Regulation 129 (e) which prescribes the construction and installation of armoured cables.

These requirements comprise electrical continuity of the metallic covering, efficient protection against corrosion and a certain minimum electrical conductivity.

It follows that all joints in the metallic covering must be efficiently and substantially made and that deterioration of the metallic covering must be guarded against.

Metallic covering is defined in Regulation 118 to mean iron or steel armouring and from this it follows that a plain lead sheath, or a copper sheath, can not in the absence of iron or steel armouring be relied upon as the earthing conductor.

The conductivity, however, of a lead sheathed armoured cable may be taken to be the combined conductivity of the lead sheath and armour, provided that both are utilized effectively by suitable bonding at every point where the armour or the lead sheath is severed.

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Steel tape armor, which is relied on for mechanical protection for cables laid in the streets, will rarely be acceptable as an earthing conductor for apparatus to comply with this Regulation, because of its relatively poor conductivity.

With tape armored cables some difficulty may be found in securing adequate conductivity at points where the armor is severed for the purpose of connection to apparatus and at joints.

Flexible metallic tube is sometimes used to enclose and protect insulated conductors; while such enclosure may afford adequate mechanical protection it does not constitute an adequate earthing conductor, and is not acceptable below ground as a substitute for armored cable.

The proviso, in the Regulation, of a minimum size of .022 square inch is important and must be observed. The exception to this proviso, relating to portable lamps and other portable apparatus of comparable current capacity, which has been added to the Regulation as applying above ground, implies that a multicore cable will be used, one core providing the earth conductor. A detached or isolated earth conductor of less area than .022 square inch would not be acceptable in any case.

Joints in Earth Conductors

(125.) - (c.) All joints in earth conductors and all joints to the metallic covering of the cables shall be properly soldered or otherwise efficiently made, and every earth conductor shall be soldered into a lug for each of its terminal connections. No switch, fuse, or circuit breaker shall be placed in any earth conductor.

The necessity for proper attention to joints must be obvious. Metal parts constituting a joint should be thoroughly cleaned and any glands or clamps should accurately fit those parts of the cable to which they are intended to make connection.

Precaution should be taken to ensure the permanence of all such contact surfaces. Rusting of bolts or corrosion of surfaces may seriously reduce the value of the contact.

A separate earthing conductor should never be attached to a bolt which also serves to fix the apparatus to its base, nor to a cover bolt, but it should be taken to an earthing terminal provided for that purpose.

The connection must be permanently secure and dependable.

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The screw or other terminal on the apparatus for the earthing conductor should be of substantial dimensions and some form of locking device is generally desirable.

Any discontinuity in the live circuit is soon evident, but an interruption, or point of high resistance, in the earth conductor may escape notice until the occurrence of an accident.

The prohibition of a switch or equivalent device in any earth conductor does not exclude the use of a switch for testing purposes between the earth plate and the neutral or mid-voltage point of the system, nor does it prevent the installation of switches to earth the neutral point of one generator only at a time when several are run in parallel.

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